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DESIGN OF AMMONIA STRIPPING TOWERS FOR WASTEWATER TREATMENT

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Environmental Protection Agency
Cincinnati, Ohio

August 1970

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DESIGN OF AMMONIA STRIPPING TOWERS FOR WASTEWATER TREATMENT

by
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Office of Research and Monitoring
Advanced Waste Treatment Research Laboratory
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DESIGN PROCEDURE FOR AMMONIA STRIPPING

Ammonia stripping towers which are similar in construction to cooling towers are believed to be an effective process for removing ammonia nitrogen from domestic and industrial wastewater. Problems exist such as scaling of the packing with calcium carbonate percipitate and the relatively large land area required. The efficiency of the tower is also highly dependent on water and air temperatures and freezing can occur if the wet bulb temperature of the air is below 32°F. Since Henry's Law constant is temperature dependent, the efficiency of the tower decreases with temperature.

A digital computer program has been developed by FWQA[1] and this program should be used if careful design is required. A good feel for the effectiveness of the process can be obtained from the graphical design scheme described below.

1. Pretreatment

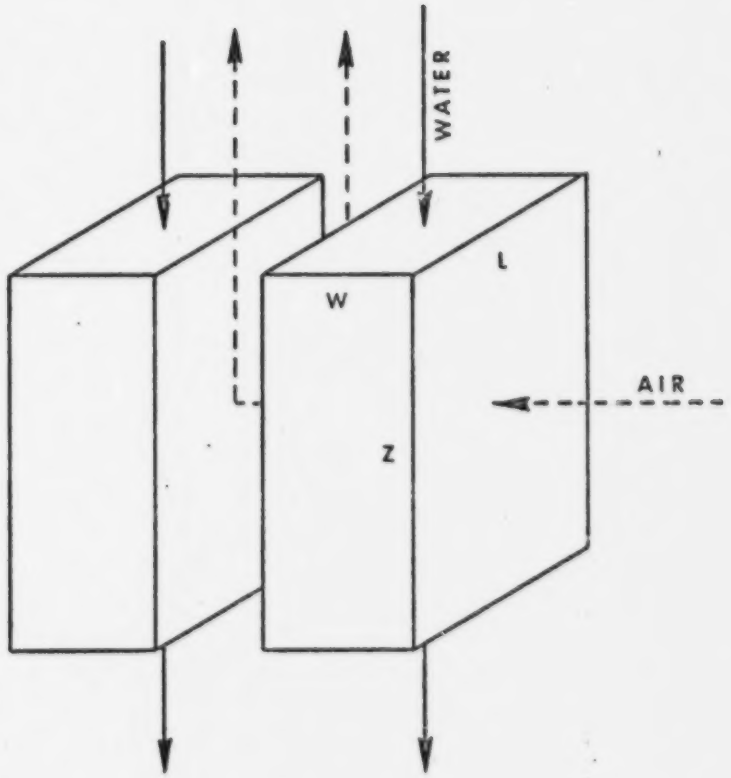
   The pH of the wastewater must be adjusted to the 9-12 range to convert ammonia to the NH_3 form which can be stripped with atmospheric air. Lime clarification is an effective process for removing both phosphorus and suspended solids from secondary effluent. It will be assumed here that ammonia stripping is used downstream of lime clarification and that the pH of the water is sufficiently high to make all of the ammonia available for stripping (about 10).

2. Performance Required

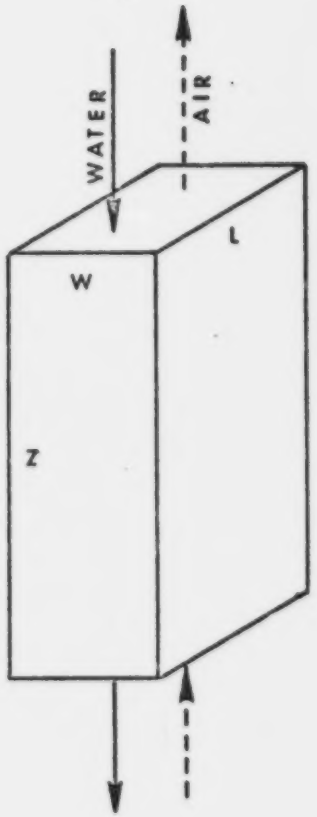
   The design requirement is the average ammonia nitrogen concentration in the effluent water stream from the tower. This value must be set initially. 90% removal of ammonia nitrogen is often taken as the design criteria.

3. Design Decisions

   The first design decision is whether to use the crosscurrent or the countercurrent configuration. The two configurations are shown diagrammatically in Figure 1. Most designers now seem to prefer the crosscurrent design although this may change as more performance data becomes available. Next, the liquid loading rate must be fixed. The range normally selected is 500-1000 lb water/hr/sq ft. The gas/liquid loading rate ratio (G/L)*, (lb air/hr/sq ft)/(lb H_2O/hr/sq ft)) is selected next. This fixes the gas loading rate. The (G/L)* ratio is normally set at 2 to 4. For countercurrent towers the (G/L)* ratio will determine the maximum percent removal possible. The tower width must also be selected by the designer. The wider the tower the less efficient the stripping operation for the crosscurrent tower. For the countercurrent tower the effectiveness of stripping is independent of the tower width. Both the



CROSSCURRENT



COUNTERCURRENT

AMMONIA STRIPPING TOWERS

FIGURE 1

ammonia concentrations and the flow are likely to vary diurnally and seasonally. The design can be based on peak or average conditions depending on the nature of the requirement for the effluent stream. In any case some excess capacity should be required for shut-down and repair or cleaning of the tower. The amount of excess capacity provided will be decided by the designer.

4. Packing Characteristics

Although some work has been done in an effort to relate the effectiveness of the packing to the dimensions (size, spacing, and surface characteristics) of the packing, this has been largely ineffective. The safest procedure is to obtain the packing characteristics from the tower manufacturer. For one type of packing used in crosscurrent operation the packing characteristic relating the Ammonia Stripping Height of a Transfer Unit to the (G/L)* ratio is shown in Figures 2 and 3. This relationship will be used in the sample problem which follows. These data were derived from test results and it is not certain that they can be used in the design of countercurrent towers.

5. Sizing Countercurrent Towers

For countercurrent operation the removal of ammonia nitrogen down the tower can be expressed by the following closed form relationship provided it is assumed that the water temperature remains constant through the tower.

$$Z/HTU = (1/(A - 1)) \log_e \left[\frac{(A - 1) X_1 + X_2 - (G/L)Y_2}{(A - 1) X_2 + X_2 - (G/L)Y_2} \right] \quad (1)$$

The subscript (1) refers to the top of the tower and the subscript (2) refers to the bottom of the tower. See Page for definitions of symbols. Henry's Law constant (m) is computed as follows:

$$m = 0.1117 e^{0.02612T} \quad (2)$$

The ammonia nitrogen concentration (Y_2) of air entering the bottom of the tower is normally set equal to zero.

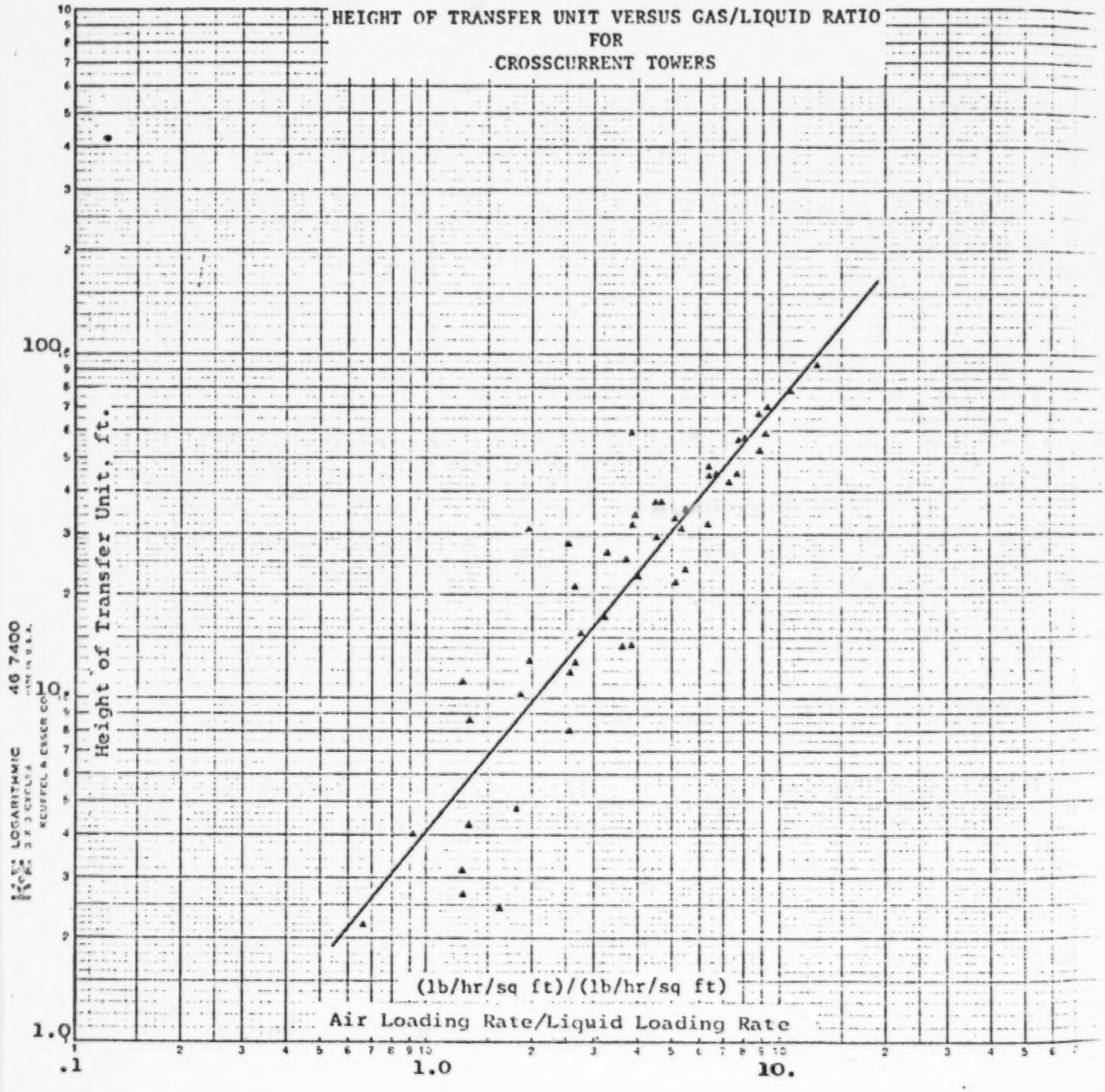

HEIGHT OF TRANSFER UNIT VERSUS GAS/LIQUID RATIO
FOR
CROSSCURRENT TOWERS
Height of Transfer Unit, ft.
100.
10.
1.0
(lb/hr/sq ft)/(lb/hr/sq ft)
Air Loading Rate/Liquid Loading Rate
.1
1.0
10.

FIGURE 2

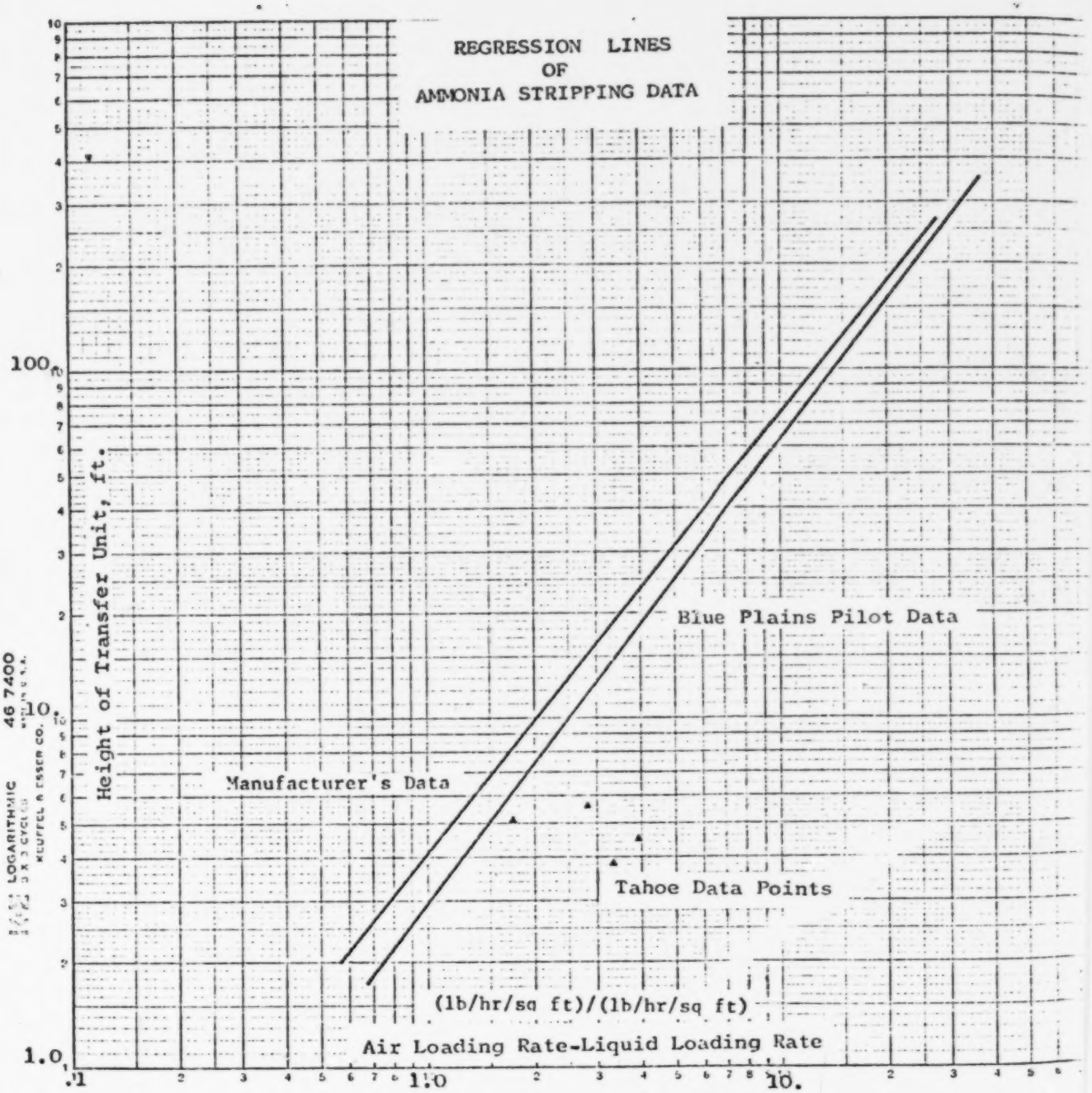

REGRESSION LINES
OF
AMMONIA STRIPPING DATA
Height of Transfer Unit, ft.
100.
10.
1.0
.1
1.0
10.
Blue Plains Pilot Data
Manufacturer's Data
Tahoe Data Points
(lb/hr/sq ft)/(lb/hr/sq ft)
Air Loading Rate-Liquid Loading Rate
46 7400
LOGARITHMIC
KEUFFEL & ESSER CO.

FIGURE 3

If the flow through the tower is given in mgd, this must be converted to lb/hr as follows: lb/hr = mgd x (8.33/24) x 10^6. The plan area of the tower is then (lb/hr)/L. The length and width of the tower can be selected in any way which gives this required plan area.

6. Pressure Drop Through the Tower

The pressure drop through the tower will determine, in part, the electrical power used by the fans. The pressure drop through the packing is directly proportional to the velocity head, $1/2\rho V^2$. Concentration of mass can be expressed as $Q = \rho AV$; where Q is lb/hr of air, A is area in sq ft, and V is velocity of air in ft/hr. Rho is air density in lb/cu ft. The gas loading rate, G, in terms of lb/hr/sq ft is, therefore, equal to ρV. The pressure drop through the tower will, therefore, be expressed as a constant times G^2/ρ. The constant is a characteristic of the packing and must be obtained from the manufacturer of the packing.

7. Sizing Crosscurrent Towers

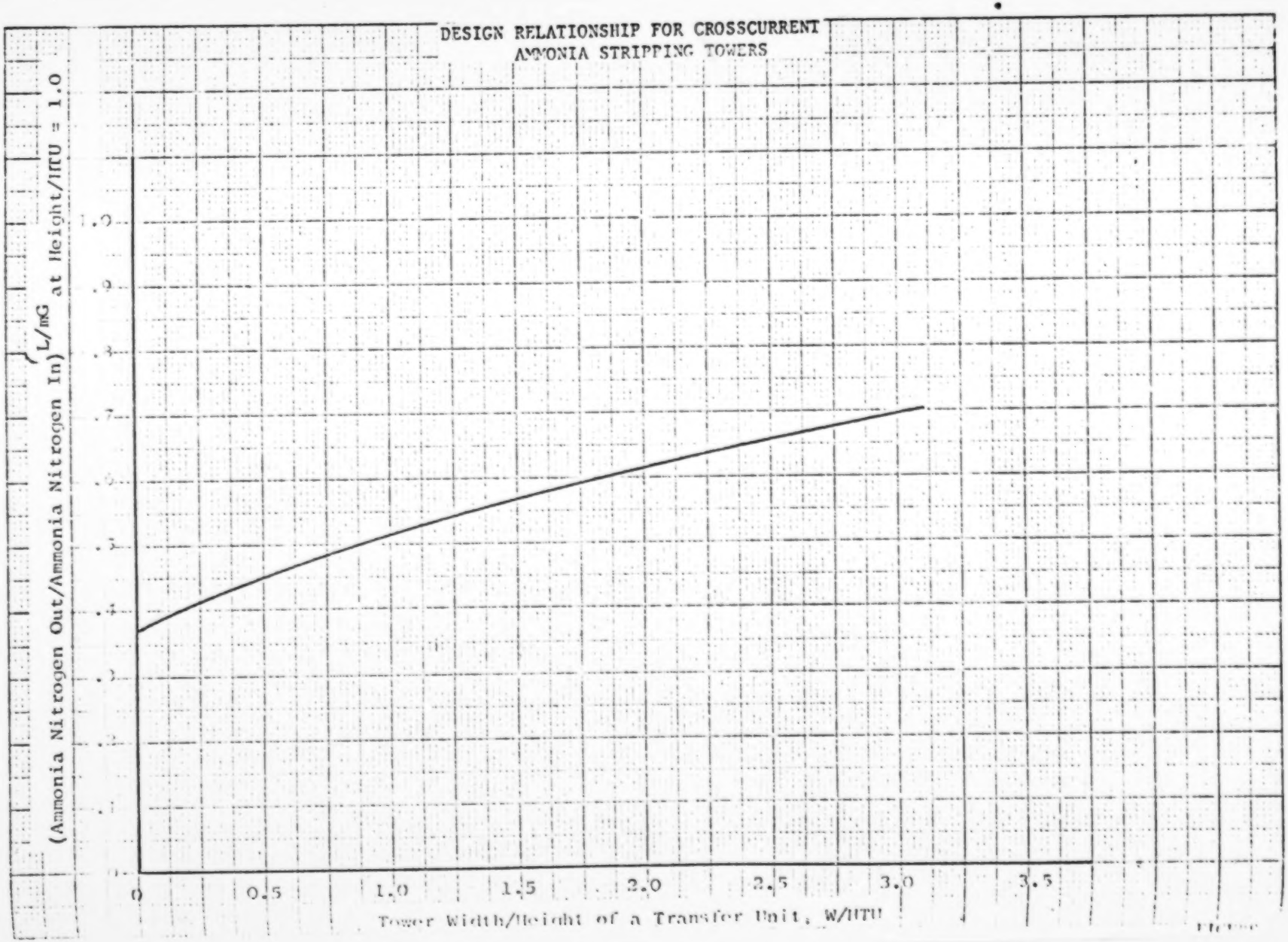
Crosscurrent towers are normally built in two identical sections (as shown in Figure 1) so that the air can flow into a channel between the two sections and out the top of the tower. For a crosscurrent tower the liquid loading rate is selected first. The total flow through the tower is divided by two and this flow is used to size one of the two sections. For example, the plan area of one section is computed as follows:

$$A = mgd/2L \times (8.33/24) \times 10^6 \qquad (3)$$

The width of the tower must be selected by the designer. Since the plan area of one section has been computed, the length equals the plan area divided by the tower width. Both sections have the same height, Z, and the procedure for finding height follows:

For a tower of infinitesimal width the removal of ammonia nitrogen down the tower can be represented by the following relationship:

$$X = X_o\, e^{-(mG/L)(Z/HTU)} \qquad (4)$$


DESIGN RELATIONSHIP FOR CROSSCURRENT
AMMONIA STRIPPING TOWERS
(Ammonia Nitrogen Out/Ammonia Nitrogen In) $_{L/mG}$ at Height/HTU = 1.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Tower Width/Height of a Transfer Unit, W/HTU

where G = gas loading rate, lb moles/sq ft/hr
L = liquid loading rate, lb moles/sq ft/hr
Z = tower height, ft
HTU = height of a transfer unit, ft
X = ammonia nitrogen concentration at Z ft down the tower, mg/l
X_o = initial ammonia nitrogen concentration at top of tower, mg/l

Since (mG/L) is a constant, X/X_o versus Z/HTU will plot as a straight line on semi-log paper. It has been found by means of computation with the digital program that for towers as finite width X/X_o versus Z/HTU always plots as a straight line on semi-log paper. The removal characteristics of any crosscurrent tower can, therefore, be found by locating one point on the straight line. It has also been discovered by means of computation that the value of X/X_o at the Z/HTU = 1.0 level from the top of the tower can be represented as shown in Figure 4. This design relationship holds over a range of influent ammonia nitrogen concentration from 20 to 2000 mg/l.

8. The cost of owning and operating the tower will depend on the design but reliable cost information must be obtained from the equipment manufacturer. Some representative cost relationships are given in Reference 1 but these cannot be used as a substitute for data from the supplier. In general the equipment cost components are 1. cost of fans, 2. cost of water pumps to deliver the water to the top of the tower, 3. cost of the structure as a function of the volume, 4. cost of the packing as a function of the volume of the tower, and 5. exterior covering and electrical installation. The principal operating and maintenance costs are electrical power for pumping water and air, operating and maintenance labor, and chemicals if required.

REFERENCES

1. Roesler, J. F., Smith, R. and Eilers, R. G., "Mathematical Simulation of Ammonia Stripping Towers for Wastewater Treatment", FWQA Publication, January 1970.

SAMPLE PROBLEM FOR CROSSCURRENT AMMONIA STRIPPING TOWER

Design data are shown on the attached form. Wastewater to be treated is municipal sewage which has been treated with primary sedimentation followed by activated sludge and then lime clarification. The packing will be assumed to have the characteristics shown in Figure 2. From Figure 2 read 9.7 feet as the height of a transfer unit corresponding to a $(G/L)^*$ of 2.0.

1. First calculate Henry's Law constant (m) from the following relationship:

   $$m = 0.1117\ e^{0.02612T}$$

   T is the water temperature in degrees F (85°F). The value of m is, therefore, 1.02866.

2. The width of one section of the tower will be 60/2 or 30 ft. Tower width over HTU equals 30/9.7 or 3.1. The grouping mG/L can be calculated as follows: 1.029(1000/29)/(500/18) = 1.277. Enter Figure 2 at W/HTU = 3.1 and read 0.702. Raising 0.702 to the 1.277 power gives 0.638. This is the value of X/X_o when Z/HTU equals 1.0. The performance of the tower can be represented by the lower line for $(G/L)^* = 2$ in Figure 5.

3. This analysis has assumed that the water temperature will remain unchanged down the tower. Actually, the water temperature will tend to approach the wet bulb temperature of the air. Since the water temperature will never go below the wet bulb temperature, we can use the wet bulb temperature as a limit of reduced performance. Repeat the above computation using 75°F for the water temperature. Henry's Law constant (m) will have a value of 0.793. The grouping mG/L will have a value of 0.985. Raising 0.702 to this power gives 0.706. The upper line for $(G/L)^* = 2$, in Figure 5, represents the limit of performance depreciation due to cooling of the water.

4. From Figure 5 read Z/HTU at the $X/X_o = 0.1$ level. The height of the crosscurrent tower to achieve an ammonia nitrogen concentration out of the tower of 2 mg/l is 5.1 x 9.7 or 49.5 ft with no temperature correction. The maximum height required with maximum cooling effect is 6.8 x 9.7 or 66 ft.

5. Since these tower heights are large, we can look at the effect of increasing $(G/L)^*$ to 4. From Figure 2 read HTU as 23.5 ft. Width/23.5 ft is 1.278. Enter Figure 4 and read 0.545 for $(X/X_o)^{L/mG}$. For 85°F mG/L will equal 2.56 and the intercept will be 0.21. At 75°F mG/L will equal 1.97 and the intercept will equal 0.302. These two lines are shown on Figure 5.

DESIGN OF AMMONIA STRIPPING TOWERS FOR WASTEWATER TREATMENT

REQUIRED DESIGN INFORMATION

1. Feed Stream Characteristics

   a. average water flow, mgd 10

   b. peak water flow, mgd 25

   c. water temperature, °F 85

   d. ammonia nitrogen concentration in water, mg/l 20

   e. pH of water 11

   f. wet bulb air temperature, °F 75

2. Required Effluent Stream Characteristics

   a. ammonia nitrogen concentration, mg/l 2.0

3. Design Decisions

   a. Liquid Loading Rate, lb H_2O/hr/sq ft 500

   b. Gas Loading Rate, lb air/hr/sq ft 1000

   c. Tower Width, ft 60

   d. Excess Capacity Factor 1.2

4. Packing Characteristics (from Manufacturer)

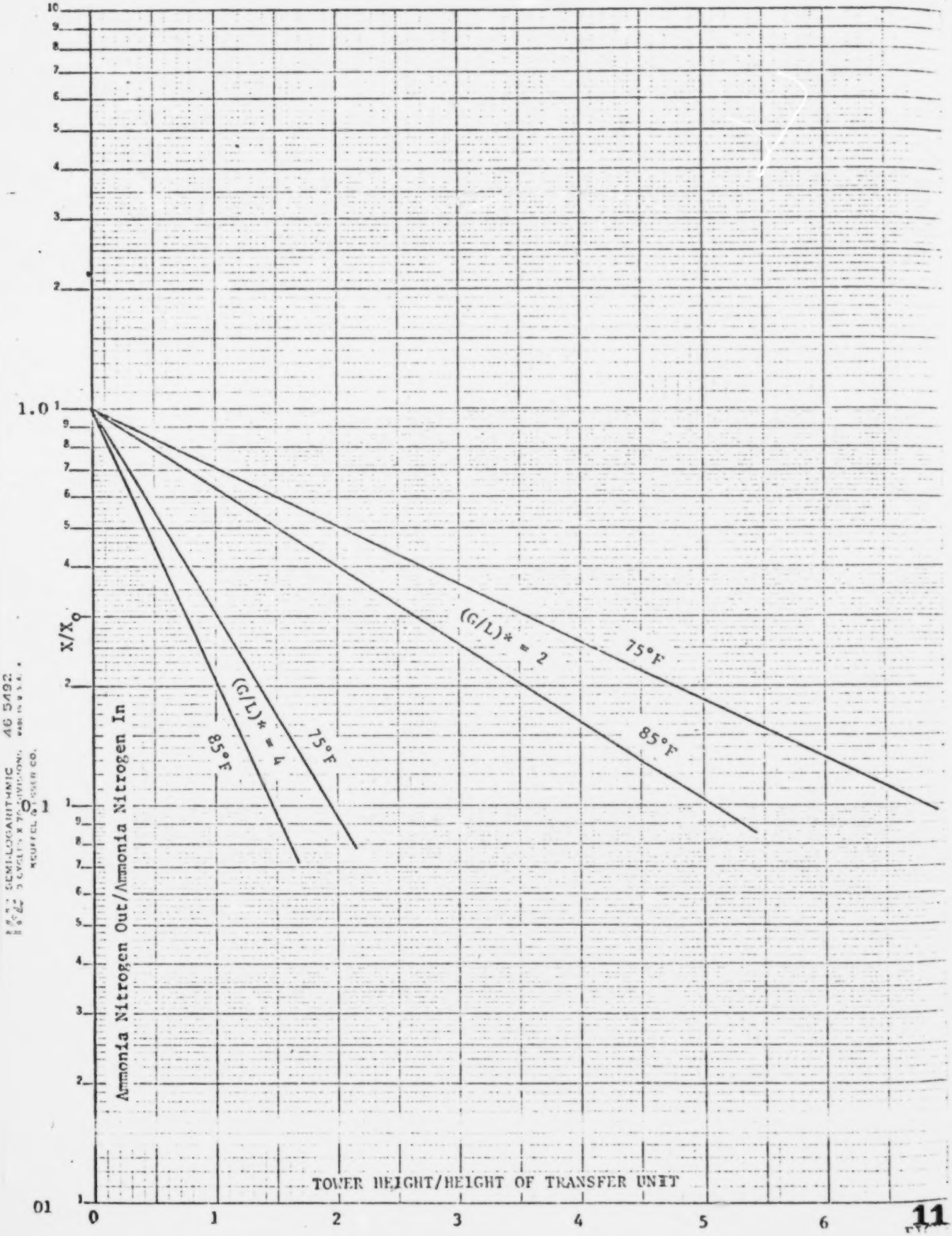
   a. Ammonia Stripping Height of a Transfer Unit (ft) versus Gas/Liquid Ratio (3b/3a)

   b. Height of a Transfer Unit (ft) for Cooling versus Gas and Liquid Loading Rates

   c. Pressure Drop Characteristics as Function of Gas Loading

5. Computation Decision (for use with computer program)

   a. size of increment, ft 1.0


Ammonia Nitrogen Out/Ammonia Nitrogen In
X/X0
1.0
0.1
0.01
(G/L)* = 2
75°F
85°F
(G/L)* = 4
75°F
85°F
TOWER HEIGHT/HEIGHT OF TRANSFER UNIT
0
1
2
3
4
5
6

6. The height of the tower at 85°F is 1.48 x 23.5 or 34.8 ft. The height of the tower assuming 75°F is 1.95 x 23.5 or 45.8 ft. We see that setting the (G/L)* ratio at 4 instead of 2 results in a shorter tower. The amount of air required, however, is not doubled. Thirty four and eight tenths times two divided by 49.5 is 1.40. At the higher air loading rate 40% more air is required. To find the optimum (G/L)* ratio the entire design must be priced and the minimum cost tower selected. This requires repetitive calculations and reasonably accurate cost data as well as mass transfer, enthalpy transfer, and pressure drop characteristics. Pressure drop and cost relationships for the packing described in Figure 2 are not known.

7. The plan area of one of the two tower sections can now be computed for the Gas/Liquid ratio of 2.0. Area = 10/2(500) x (8.33/24) x 10^0 = 3475 sq ft. Since the width of one section was 30 ft, the length of the tower is 3475/30 or 116 ft. The crosscurrent tower for a Gas/Liquid ratio of two will consist of two sections 30 ft wide, 116 ft long and 55-60 ft high.

8. To complete the design, the pressure drop through the two sections must be computed from the manufacturer's data. The cost of structure, packing and pumps must be computed. The electrical power consumption can be computed from the air pressure drop and the height of the tower together with the volume flows of air and water.

SAMPLE CALCULATION FOR COUNTERCURRENT AMMONIA STRIPPING TOWER

The same design conditions used for the crosscurrent tower will apply to the countercurrent tower. Since we have no valid height of a transfer unit for packing used in the countercurrent configuration, we will use the 9.7 ft for purposes of demonstration.

1. In most instances the water will be cooled within the tower and Henry's Law constant will be reduced resulting in a less efficient tower. This effect can be evaluated in the computer program but not in hand calculations. Substitute into equation (1) for 85°F water and then for 75°F water. The grouping mG/L has a value of 1.277 at 85°F and 0.985 at 75°F. At 90% removal the value of Z/HTU for 85°F is 3.906 corresponding to a tower 37.9 ft high. The corresponding crosscurrent tower was 49.5 ft high. For 75°F the value of Z/HTU computes to be 9.82 which multiplied by 9.7 ft gives a tower height of 95.3 ft. This is larger than the 66 ft computed previously for the crosscurrent tower. This demonstrates how the countercurrent design can become prohibitive if performance above a certain level is demanded.

2. The plan area of the countercurrent tower assuming 85°F water can now be computed as follows: $A = mgd/L \times (8.33/24) \times 10^6 = 10/500 \times (8.33/24) \times 10^6 = 6942$ sq ft which is equal to the area of the two sections of the crosscurrent tower. If we take the width as 60 ft, the length is again 116 ft. The countercurrent tower has the same plan area but is, perhaps, shorter in height. This calculation shows the necessity for consideration of the cooling effect within the tower. The digital computer program computes this effect but the height of a transfer unit for enthalpy transfer must be known and this information is normally available only from the manufacturer.

DEFINITIONS OF ALGEBRAIC SYMBOLS

mgd	millions of gallons of water per day
mg/l	milligrams per liter
lb	pounds
hr	hour
sq ft	square feet
cu ft	cubic feet
G	gas loading rate, lb moles air/sq ft/hr
L	liquid loading rate, lb moles water/sq ft/hr
Z	tower height, ft
HTU	height of a transfer unit, ft
X	ammonia nitrogen concentration in water, mg/l
Y	ammonia nitrogen concentration in air, mg/l
m	Henry's Law Constant, mole fraction in air/mole fraction in water
A	m(G/29)/(L/18)
T	water temperature, degrees F
ρ	air density, lb/cu ft
V	air velocity, ft/hr
(G/L)*	(lb air/hr/sq ft)/(lb water/hr/sq ft)